PATENT SPECIFICATION

(11) 1 475 378

(21) Application No. 40593/74 (22) Filed 18 Sept. 1974
(31) Convention Application No. 426377 (32) Filed 19 Dec. 1973 in
(33) United States of America (US)
(44) Complete Specification published 1 June 1977
(51) INT CL² G02F 1/13
(52) Index at acceptance
G2F 23E 25F 25P1 CD
G5C 342 372 374

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(54) LIQUID CRYSTAL DISPLAY DEVICE

(71) We, INTERNATIONAL BUSINESS MACHINES CORPORATION, a Corporation organized and existing under the laws of the State of New York in the United States of America, of Armonk, New York 10504, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates generally to electro-optic devices employing liquid crystals and more particularly to alpha-numeric display devices using homeotropically aligned positive nematic liquid crystal material.

The nematic materials are organic compounds whose molecules have an elongated rod like structure. The compounds generally contain polar groups and the resulting dipole moment is at some angle with the long axis of the molecule. Depending on the position of these polar groups in the molecule and their respective strength, the angle between the molecular dipole moment and the long axis can be less than 45°. Such compounds are herein defined as positive nematic when the component of the dipole moment along the long axis is larger than the component perpendicular to the molecular axis. There also exists a class of nematics having a large angle between the dipole moment and the molecular axis. These compounds are called negative nematic because the component of the dipole moment along the molecular axis is smaller than the perpendicular component. All nematics, whether positive or negative are birefringent of uniaxial symmetry. The optical axis is always in the direction of the long axis of the molecule.

Liquid crystal materials at certain temperature ranges, including those around room temperature, exist in an intermediate state between highly ordered crystalline state and the randomly ordered liquid state. In nematic liquid crystals, molecules in a given area or domain tend to be aligned with their long axis parallel. When such materials are placed between electrodes and an electric field is applied, the molecules tend to rotate and realign themselves parallel to one another in a direction determined by the dipole moment of the molecule. Thus when an electric field is applied and the molecules rotate, the direction of the optical axis will change. Heretofore, commercial field effect devices contain liquid crystal material in parallel alignment. In such cells a preferred direction is established by rubbing or other means and the cell is arranged such that the preferred direction of the lower surface is perpendicular to the preferred direction of the upper surface. Thus the orientation is twisted over 90° through the cell thickness. When viewed in the quiescent state between crossed polarizers, the cells are bright. When an electric field is applied the molecules rotate and the optical axis is substantially parallel to the field and the viewing direction and, therefore, the cell is dark. It has been found that it is difficult to achieve and maintain under prolonged use a uniform parallel alignment over the whole area of the display. Consequently, such cells even when new do not exhibit uniform brightness over the entire area and soon fail to operate.

Most nematic materials tend to align randomly at the substrate surface. However, additives are known which have been used with negative nematic material and which cause the molecules to be aligned perpendicular to the substrate surface in the quiescent state. Such alignment is termed homeotropic. Such additives, while heretofore used only with negative nematics, have been found to be equally useful in causing homeotropic alignment for positive nematics. Starting with homeotropically aligned material, the direction of the electric field is usually parallel to the viewing direction if negative nematic material is used and conversely the electric field must be perpendicular to the viewing direction if positive nematic material is used. However, negative material when subjected to an electric field exhibits turbulent liquid flow. The phenomenon is well known and termed "Dynamic Scattering". The turbulence partially depolarizes light incident

on the material and such cells show very poor contrast between the "off" and the "on" state. As is described in U.S. Patent 3,687,515, a display can be constructed using negative nematic material with the field direction oriented perpendicular to the viewing direction with dynamic scattering being relied upon to produce partial depolarization in the "on" state. Again, the contrast is poor. Positive material cannot show dynamic scattering.

According to the invention there is provided a liquid crystal device comprising: two spaced apart parallel transparent members, at least one pair of electrodes formed on the facing surface of one of said members, a positive nematic liquid crystal material (as herein defined) filling the space between said members, said material being homeotropically aligned with respect to the facing surfaces of said members in the absence of an electric field, means to apply an electric field across said liquid crystal material between the electrode pair to create an electric field parallel to the surface of said members, and two crossed polarizers located on an optical path perpendicular to the facing surfaces of said members and on opposite sides of the structure formed by said transparent members and said liquid crystal material.

In a display embodying the invention the quiescent state (the "off" state) is viewed in the direction of the optical axis of the material (i.e. along the optical path) and therefore the cell will be uniformly dark between crossed polarizers. The electric field is applied such that the molecular orientation is changed by almost 90°. The film is now birefringent and thus appears bright between crossed polarizers if it is of the correct thickness, i.e. does not act as a full wave plate.

The invention will be further explained, by way of example, with reference to the accompanying drawings, in which:

Figs. 1A and B are highly schematic drawings, partially in section, illustrating the structure and operation of an embodiment of the device of the invention.

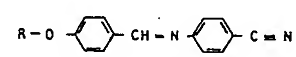
Fig. 2 is an exploded view of a numeric display cell having a structure in accordance with the invention.

Figs. 3A and B are schematic isometric views of an electro-optic device embodying the present invention.

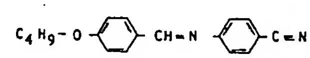
Turning now to Fig. 1A, a liquid crystal cell 11 is formed having transparent substrates 15 and 17 of a material such as glass, plastics, or other inert material having good light transmissive characteristics. The substrates have plain opposed parallel faces and on the inner face of substrate 17 are formed electrically conductive electrodes 19 and 21 of the order of 1,000 to 3,000 Å in thickness. Examples of materials which can be employed for making such electrodes include In_2O_3, tin oxide, and chromium. Sandwiched between substrates 15 and 17 is a layer 13 of liquid crystal material whose molecules 27, as shown schematically, have their long axes in a direction perpendicular to the planes of the substrates. The spacing between substrates 17 and 15 is determined by any suitable means such as raised portions at the edges of the substrates themselves or shims or gaskets 12 of any suitable inert material such as glass or plastics. The preferred spacing is maintained from about 0.5 to 1 mil and the gaps between electrodes 19 and 21 range from about 1 to 20 mils. Electrodes 19 and 21 are connected to electrical leads 24 and 25 respectively, with electrode 19 connected to a voltage source 26 through switch 28.

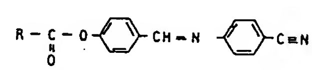
In the quiescent state when viewed through crossed polarizers (not shown) in the direction of the optic axis, a diffused light source (not shown) behind substrate 17 does not pass light through liquid crystal layer 13 and the field appears uniformly black. When switch 28 is closed an electrical field is applied between electrodes 19 and 21 in a direction parallel to the planar surface of substrate 17. The molecules 27A of liquid crystal material layer 13 are caused to rotate or twist to orient themselves such that the long axis of the molecules are parallel to each other between the electrodes and parallel to the surface of substrate 17. This causes a change in the optical properties so that in the viewing direction the liquid crystal material is now optically anisotropic (birefringent) and appears bright between the crossed polarizers. Outside of the area defined by the electrodes, the crystal alignment is unaltered and the field remains black. The alignment is a cooperative effect and thus it has a voltage threshold rather than a field threshold.

Examples of suitable positive liquid crystal materials for layer 13 are represented by the following formulas:

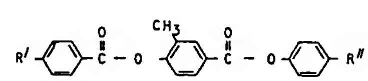
A.) 

where $R=C_nH_{2n+1}$ and $n=4$ to 6 such as

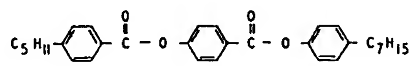


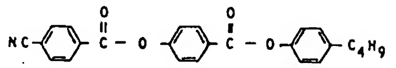
B.) 

where $R=C_nH_{2n+1}$ and $n=4$ to 6 such as C_6H_{13}

C). 

where $R'=C_nH_{2n+1}$ and $n=4$ to 6
where $R''=C_nH_{2n+1}$ and $n=4$ to 7 such as



D). 

These molecules have dipole moments in which the component in the direction of the long axis of the molecule is greater than the component in the direction perpendicular to the long axis of the molecule.

It has been found that homeotropic alignment of positive nematic materials can be achieved by the incorporation of suitable additive materials which are long chain alkyl pyridinium or quaternary ammonium salts. Such materials have been described as suitable additives to achieve homeotropic texture for negative nematic materials. For example, compounds described in U.S. Patent 3,656,834 (U.K. Specification 1,315,578) which are compounds of the formula $RR_3'N^+N^-$ wherein R is selected from the group consisting of alkyl radicals having 10 to 24 carbon atoms, R' is selected from the group consisting of methyl and ethyl and X^- is selected from the group consisting of anions derived from simple acids. Typical examples of specific compounds are hexadecyl pyridinium bromide, dodecyl pyridinium bromide hexadecyl trimethyl ammonium bromide, etc. The materials are employed in amounts in a range of from about 0.25 to 2.5×10^{-4} mol fraction of liquid crystal material depending upon the solubility characteristics of the particular nematic liquid crystal material which is employed.

It was found that with a test pattern in which the electrode separation was about a 5 mil gap and the spacing of the substrates was about 0.5 mil, employing the positive nematic material of type C with 7×10^{-4} mol fraction of hexadecyl pyridinium bromide as an aligning agent, the cell had a threshold of about 8 volts and the display was uniformly black except where the voltage was applied. Lower thresholds have been obtained with mixtures of compounds of the types A and B.

Fig. 2 is an exploded view of a typical cell arranged to produce a numeric display with a 7 segment electrode pattern of opposed electrode pairs 31—32, 33—34, 35—36, 37—38, 39—40, 41—42 and 43—44 formed of In_2O_3 on a glass substrate 45. One electrode of each pair is connected to ground 47 and the second electrode of each pair is connected to suitable control and addressing circuitry schematically represented by box 49. Spacer 51 of the plastic material Teflon (du Pont trademark for polytetrafluorethylene) having a thickness of about 0.5 mil and glass substrate 53 complete the assembly and provide the space for the inclusion of the liquid crystal material which was homeotropically aligned by mixing it with a suitable additive as described above.

Figs. 3A and B are schematic illustrations of the optical system employing a cell 30 of the invention such as the one illustrated in Fig. 2 including crossed polarizers 61 and 62, a lamp 63 and a diffuser 64 to provide diffused backlighting. In the quiescent state, light ray 65 is polarized by polarizer 62 and passes through cell 30 without change such that it is stopped by polarizer 61 and the cell appears dark. As shown in Fig. 3B upon the application of a field, to areas of the cell between selected electrode pairs the liquid crystal material acts on the light beam such that it is elliptically polarized in the areas of the applied field so that light now passes polarizer 61 and is observed as bright areas in the space between the electrode pairs where the voltage is applied such that any selected numeral from 0 to 9 is displayed.

The cells of the invention have the advantage of uniform brightness and long life because homeotropic alignment of the liquid crystals can be readily achieved and maintained as opposed to parallel alignment. Because the electrodes are formed on a single substrate, precise electrode patterns and spacings are easy to obtain by conventional photolithographic techniques and this permits the use of a positive nematic homeotropic aligned material in liquid crystal displays.

WHAT WE CLAIM IS:—

1. A liquid crystal display device comprising:

two spaced apart parallel transparent members,

at least one pair of electrodes formed on the facing surface of one of said members,

a positive nematic liquid crystal material (as herein defined) filling the space between said members, said material being homeotropically aligned with respect to the facing surfaces of said members in the absence of an electric field,

means to apply an electric field across said liquid crystal material between the electrode pair to create an electric field parallel to the surface of said members, and

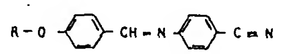
two crossed polarizers, located on an optical path perpendicular to the facing surfaces of said members and on opposite sides of the structure formed by said transparent members and said liquid crystal material.

2. The device of claim 1 wherein the liquid crystal material is homeotropically aligned by the inclusion of an additive material.

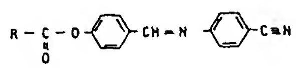
3. The device of claim 2 wherein the additive material is selected from the group consisting of long alkyl chain pyridinium salts and long alkyl chain quaternary ammonium

salts in amounts of from 0.25 to 2.5×10^{-4} mol percent of liquid crystal material.

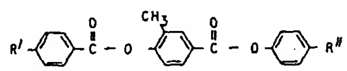
4. The device of any preceding claim wherein said liquid crystal material is selected from a compound having the formula:

A.) 

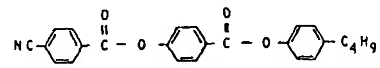
where $R=C_n H_{2n+1}$ and $n=4$ to 6

B.) 

where $R=C_n H_{2n+1}$ and $n=4$ to 6 such as C_6H_{13}

C). 

where $R'=C_n H_{2n+1}$ and $n=4$ to 6 and $R''=C_n H_{2n+1}$ and $n=4$ to 7 or

D.) 

5. The device of any preceding claim wherein said members are spaced apart 0.5 to 10 mils, said electrodes are from 1,000 Å to 3,000 Å in thickness and the gap between said electrode pairs is 1 to 20 mils.

6. The device of any preceding claim including a plurality of said pairs of electrodes and means to apply an electrical potential to selected pairs of said electrodes to produce representations of alpha-numeric characters.

7. A liquid crystal display device substantially as described with reference to the accompanying drawings.

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Agent for the Applicants.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1977
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1475378 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

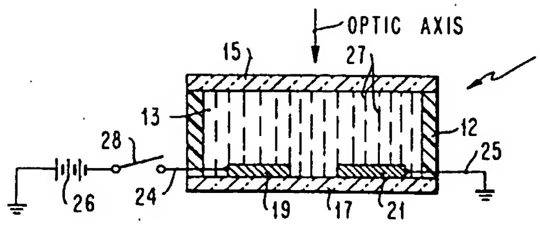


FIG. 1A

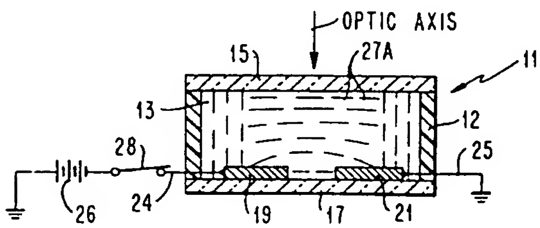


FIG. 1B

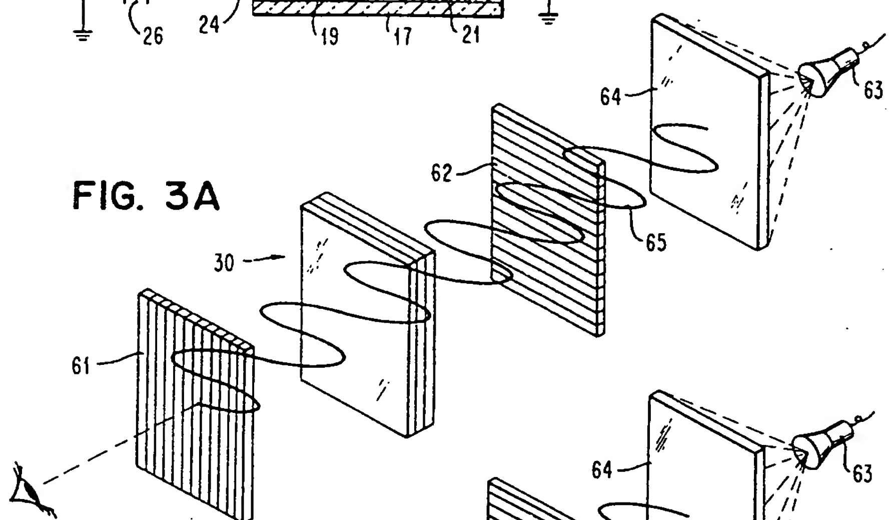


FIG. 3A

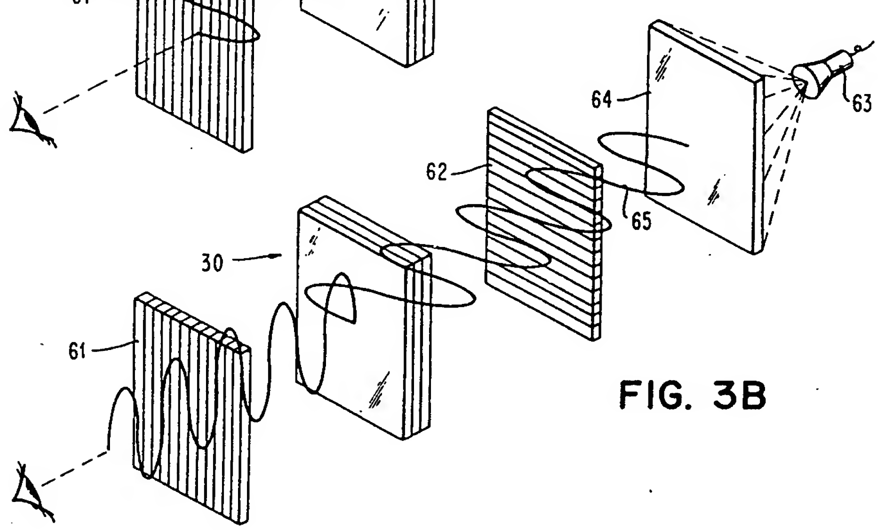
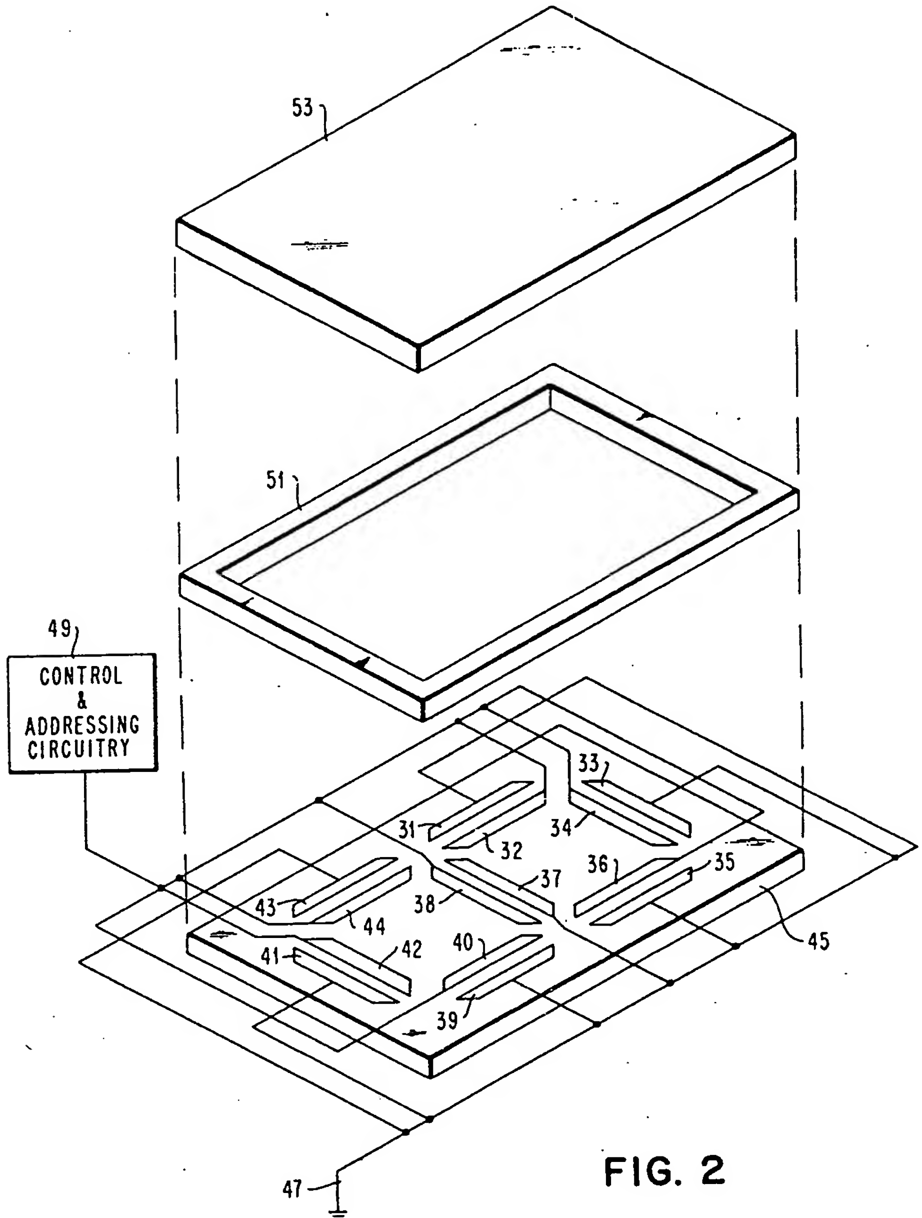


FIG. 3B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CONTROL
&
ADDRESSING
CIRCUITRY
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FIG. 2